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Observations of Azimuthal Asymmetry for Certain FRC Operating Regimes*

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The FRX-C/LSM experiment has been operated with additional diagnostics for studies of FRC structure in the θ-pinch source. Data were taken over ranges of fill pressure and bias field that lead to the formation of FRCs with confinement properties that are consistently good (e.g. at 3 mtorr at 0.7 kG bias) and consistently poor (e.g. at 5 mtorr at any bias). The pertinent diagnostics were end-on soft x-ray imaging, arrays of external B_θ and B_r probes, and five chords of interferometry. The data show that easily observed departures from azimuthal (θ) symmetry occur in some cases and that further research into the cause and nature of these asymmetries would benefit our studies of FRC stability and confinement.

Over 150 shots were taken in which single-frame, end-on, soft x-ray images were recorded with a pinhole camera. The camera was located on the symmetry axis at a distance of 9.2 m from the LSM coil midplane. It recorded photons emitted from the FRC in the 50 to 100 eV range with a spatial resolution of 14 mm and an exposure time of 2 μs. Fill pressures ranging from 2 to 10 mtorr and image times ranging from 0.5 to 150 μs were used in this work. The images obtained show outlines of the hot plasma edge that range from the circular and smooth to the misshapen and highly fluted ($n \sim 10$). FRC images with circular outlines may be characterized further by the strength of the intensity dip centered on $r=0$. Comparison of these snapshots with confinement parameters shows some correlation (strongly fluted shots never have good τ_ϕ) but not enough to indicate that either the edge shape or the central dip is a strong determiner of the quality of FRC confinement. The origin of the flutes is of interest, and it has been suggested that the inward radial acceleration at peak axial contraction may give rise to a "lower hybrid gravity drift" instability.[1] In addition to looking at edge shape, work has begun on examining the x-ray image intensity corresponding to the interior of the FRC. Low n distortions are observed in the few representative shots that have been analyzed.

Signals from arrays consisting of six B_r probes and twelve B_θ probes also indicated notable departures from a symmetric equilibrium.[2] Unlike the x-ray photos, the external probes gave full temporal coverage but had relatively limited spatial resolution. The

observed asymmetries generally develop after the peak of axial contraction but before the FRC equilibrium is fully established. It is found that τ_ϕ correlates reasonably well with a rough measure of asymmetry (the maximum observed B_θ during the quiescent phase) showing that poor magnetic symmetry is associated with degraded confinement. A comparison of the B_θ probe signals with the timing of the soft x-ray images gives a clue about those cases in which circular, symmetric images were obtained for FRCs that nonetheless showed poor confinement. In such instances, the B_θ probes often show a strong asymmetry developing later in the shot, after the camera was triggered.

A 3-D resistive MHD code (FRC3D) has been used as an aid to the interpretation of the above experimental results. In addition to providing well characterized FRC distortions for comparison with data, this work has given an appreciation of the potential importance of modes other than the $n=1$ tilt. For example, the growth rate of the $n=1$, $m=2$ "bending" mode was computed to be 7.8 μs in contrast to 5.4 μs for an $n=1$, $m=1$ tilt of the same equilibrium.[3] However, the observed distortions in x-ray intensity and magnetic field exceed those calculated from the simulations. Furthermore, large symmetry perturbations in the MHD simulations are followed by rapid disruption of the FRC; this is not the case under optimal conditions in the experiment.

In summary, our initial observations suggest that significant correlations may exist between FRC confinement properties and departures from symmetry of the sort observed with external magnetic probes and soft x-ray imagining. Unfortunately, the spatial and temporal coverage of the diagnostics used to date was insufficient to establish the degree of such a correlation or its determining factors. Many open questions remain. To what extent can the appearance of asymmetry (or the degradation of confinement) be considered as an isolated event as opposed to a continuing process? Do the asymmetries of importance have a reproducible structure, possibly characterized by definite modes (m,n)? Are measurements of external features adequate or is it the internal FRC structure that counts? Do the observed asymmetries develop from a symmetric equilibrium state or are they artifacts of distortions introduced during formation?

It is not hard to conceive of improvements to the principal diagnostics that will help resolve these issues. In the case of the external probe arrays, increasing the number of probes and arranging for uniform coverage in z and θ is essential. Our results show that the B_r probes are redundant and only a B_θ array is needed. Although it would require a major effort, moving the array inside the quartz tube and closer to the separatrix would

increase sensitivity to FRC distortions. In the case of the soft x-ray diagnostic, a faster cycle for film changes or, ideally, direct electronic image recording would be an obvious improvement. Work on computational image enhancement has already begun.[4] Objective numerical measures of image asymmetry are needed for both the separatrix shape and the intensity profile. Finally, a capability for multiple images during a single shot would bring obvious benefits. In any event, experience gained from the B_θ probe signals should indicate, for a given operating condition, the best times to trigger the camera. With regard to the numerical simulations of unstable behavior, until more is known about the experimental circumstances we cannot expect them to provide more than a qualitative basis for analyzing the data. The internal MHD modes treated so far, based on centered, symmetric equilibria, simply do not generate enough B_θ at the probe locations.

Whether or not continued investigation of FRC symmetry and confinement yields a concrete relationship between the two, and whether or not such a relationship can be traced to a definite mechanism, such studies ought to give us a better appreciation of the factors that introduce scatter into confinement data and a more objective means for deciding which data ought therefore to be considered "typical" for given global conditions.

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